INTERMITTENT VENTILATION DURING EXCAVATION OF A BURIED AVALANCHE PATIENT - AN EXPERIMENTAL PROSPECTIVE MANIKIN PROOF OF CONCEPT

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ABSTRACT: Complete burial in an avalanche leads to asphyxia-induced respiratory suppression and respiratory arrest. The timeline is influenced by the properties of the debris as well as the crystalline structure. Once respiratory arrest has occurred, hypoxia leads within minutes to severe, irreversible neurologic damage, followed by cardiac arrest due to absolute depletion of oxygen. Due to insulation of multi-layer clothing as well as the air content of the debris, the cooling rate of avalanche patients is, with very few exceptions (Pasquier et al., 2015; and Rauch et al., 2023), within a low 1°C to 3°C per hour (Brown et al., 2012; and Putzer et al. 2010). Therefore, the neuroprotective effect of hypothermia is in most cases too slow to prevent severe neurologic damage. In companion and fast organized rescue (i.e. ski patrol), reaching the head of the patient within 5 to 15min of burial duration is realistic. While many patients will already suffer severe, non-self-recoverable respiratory suppression or respiratory arrest, the majority will not have suffered cardiac arrest yet. Without rescue breaths, these patients are very likely to progress towards a further depletion of oxygen, neurologic damage and cardiac arrest. AvaLife sets as first priority a good neurologic outcome for the patient by reversing the respiratory problem with immediate first responder rescue breaths. The most likely position of the patient will be prone. Initiating rescue breaths in this position while the pelvis and lower extremities may still be firmly packed in the snow is extremely challenging. Completely freeing the entire patient takes at least 5 to 10 min. We developed a protocol which brings the airway in a position compatible with rescue breaths. Further, rescue breaths are performed continuously (when space and resources allow for it), or intermittently (intermittent ventilation, iVent). These strategies allow one rescuer to eventually completely free the patient while giving sequences of five rescue breaths every ~30 seconds. CPR for avalanche patients in hypoxic cardiac arrest remains important but second priority. Following AvaLife's Greatest Good for the Greatest Number strategy, CPR duration is limited to 6 min in case of multiple burials/patients and shortage of resources.

KEYWORDS: avalanche rescue; asphyxia; respiratory arrest; rescue breathing; intermittent ventilation; iVent; companion rescue.

1. INTRODUCTION AND SCOPE

The goal of this study is to investigate how the probability of survival and neurologic outcome of normothermic, non-fatally injured, completely buried subjects can be improved by optimizing the rescue and medical treatment priorities from moment the head and chest of the avalanche patient are exposed.

Complete avalanche burial can produce airway obstruction, rebreathing carbon dioxide, impaired oxygen diffusion through dense snow, restricted chest movement, progressive hypoxemia and hypercapnia, respiratory suppression, respiratory arrest, irreversible hypoxic brain damage and finally hypoxic cardiac arrest.

The project proceeded chronologically from outcome evidence, through identification of the pre-arrest treatment window, to burial-position analysis, test of rotational ability and rotational technique with participants buried from the pelvis

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down to their feet, manikin testing, work-allocation design, cadence testing, a practical timekeeper strategy and verifying the in-field ventilation success rate. Its goal was to develop a procedure that gives immediate effective rescue breaths while excavation continues.

2. CLINICAL PRIORITY BEFORE CARDIAC ARREST

2.1 Why avalanche patients in normothermic, hypoxic cardiac arrest are not first priority

Métrailler-Mermoud et al. (2019) reported 66 avalanche patients already in out-of-hospital cardiac arrest. None survived to hospital discharge despite 93% guideline-concordant critical decisions; seven became organ donors. In the authors' pooled analysis of 339 avalanche cardiac arrests, 14 (4.1%) survived and only 6 (1.8%) survived with Cerebral Performance Category (CPC) 1 or 2. Neurologically intact survival is therefore very rare once prolonged asphyxia and hypoxia have caused normothermic cardiac arrest.

Even when the head and chest are freed, in a complete avalanche burial, it is difficult to detect vital signs, unrealistic to immediately determine the heart rhythm of the patient and will take a considerable amount of time to bring the patient in a chest compression compatible position and place. Chest compression should not be neglected, however, the immediate focus on extrication of the head is clearing the airway and providing rescue breaths. The higher-yield target is the still-perfusing patient with severe respiratory suppression or respiratory arrest, in whom oxygen delivery can realistically reverse the immediate cause, therefore limit irreversible brain damage and avoid cardiac arrest. In case of multiple burials and shortage of resources, the 1.8% figure justifies limiting the CPR duration to 6 minutes, which aligns with the AvaLife 'Greatest Good for the Greatest Number' framework and its Monte Carlo foundation (Genswein et al., 2022; Reiweger et al., 2017).

2.2 The first 30 min contain an under-recognized group of patients in respiratory suppression

The proportion of avalanche patients in severe respiratory suppression or respiratory arrest after uncovering the head is not known. These patients extricated within the first 30 min constitute a clinically important group. Strapazzon et al. (2021) and Eisendle et al. (2025) have shown that the duration of the window of opportunity in which the majority of the patients only suffer from reversible respiratory suppression is considerable, and therefore, the likelihood that companion rescuers and fast organized rescuers frequently reach the head of the patient within this timeframe is realistic. Strapazzon et al. (2021) performed 36 artificial air-pocket tests involving 12 healthy adults in a field trial. The 4 L cylindrical air pocket had a lower surface-to-volume ratio compared to the complex shape of interconnected air spaces that naturally form around the patient's head, making the test more challenging. Out of 36 test subjects, 18 continued for 30 min. Out of the 18 tests that had to be stopped earlier, either due to $SpO_2 \leq 75\%$ or at participant's request, only approximately four were stopped between 8 and 10 min and approximately another four between 12 and 15 minutes. Cerebral oxygenation fell particularly fast in high-density snow (Strapazzon et al., 2021). Eisendle et al. (2025) conducted a clinical trial involving 12 healthy adults who were buried in a prone position in dense snow at least about 50 cm deep with only a minimal respiratory cavity. The median time to reaching the $SpO_2 < 80\%$ stop criterion was 11.2 minutes (Eisendle et al., 2025). While both studies cannot ethically continue to clinical respiratory arrest, they give a clear indication that respiratory arrest is, for the majority of buried subjects, unlikely to occur < 10 min. The applied termination criteria, SPO2 ≤ 75% and SPO2 < 80%, are significantly above the threshold for imminent respiratory arrest. This suggests the actual time to respiratory arrest is likely longer, or the high cutoff criteria might compensate for unsimulated field trial effects, like stronger chest compressions during a real avalanche. After respiratory arrest, there still will be some time until oxygen is depleted to the level at which cardiac arrest will occur. Soar et al. (2021) states that animal studies show that in asphyxia, cardiac arrests occur at a variable time between 4 and 11 min after breathing stops, and conclude «that this time period provides an opportunity to prevent cardiac arrests by correcting hypoxia. Observational data of intensive care admissions after hanging show good survival and neurological function when asphyxia does not progress to cardiac arrest, whereas hypoxic ischaemic brain injury is very common in those who progress to cardiac arrest» (Soar et al., 2021). These conclusions are equally supported by de Charentenay et al. (2020) in an analysis of the outcomes in 886 critically ill patients after near-hanging injury. Rauch et al. (2024) found a survival rate of about 60% after a 20-minute burial. Since asphyxia/hypoxia-related cardiac arrest accounts for approximately 75% of avalanche deaths, this 60% survival rate suggests many patients are not yet in cardiac arrest but are experiencing severe respiratory suppression or even respiratory arrest. The counterargument would

be hardly compatible with the 95.9% mortality rate among avalanche victims in cardiac arrest reported by Métrailler-Mermoud et al. (2019).

Cooling during this early state of burial is too low to be neuroprotective. Clothing and snow-air insulation often make the cooling gradient too slow to lower cerebral metabolic demand before hypoxic injury (Strapazzon et al., 2021; Van Tilburg et al., 2024).

After the face is exposed, complete body access commonly requires at least another 5 - 10 min. Untreated respiratory suppression or arrest during that time allows oxygen saturation to continue declining, which worsens irreversible brain damage and increases the likelihood of hypoxic cardiac arrest.

2.3 Alignment with ERC 2025

The 2025 ERC First Aid guideline recommends immediate actions for life-threatening conditions that may progress to cardiac arrest, and the ERC Special Circumstances guideline emphasizes airway management and ventilation in short-burial avalanche asphyxia (Djärv et al., 2025; Lott et al., 2025). The proposed protocol aims to ventilate the patient as soon as possible and continuously, addressing the prior condition of respiratory suppression or arrest while circulation remains intact despite the pelvis and legs being buried in the snow.

3. METHODS: DEVELOPMENT SEQUENCE

3.1 Burial positions/geometry

Published position data indicate that 45% of buried avalanche patients are prone (Kornhall et al., 2016). This finding served as a starting point for a series of interviews with highly experienced avalanche rescuers. These interviews helped refine our understanding of the scenario, the proposed procedure and ensured the protocol addressed the research questions. This understanding is crucial to determining the criteria rescue and medical algorithms must meet, as well as preparing companion and organized rescuers for the real emergency.

3.2 Ventilation compatible airway-position test

The first practical development step tested which airway positions allowed effective rescue breaths. An AmbuMan Wireless CPR manikin (Ambu, Ballerup, Denmark) was positioned starting at 120° from the standard ventilation position, in which the head would be pointing straight upwards. This angle was reduced in 10° steps until ventilations were ergonomically feasible. Quantitative success of ventilation was monitored with the recording mode of the AmbuMan Wireless software set to ventilation-only mode. The project's manikin target range was 500 - 600 mL, and the principal feasibility endpoint was delivery at or above the preset 500 mL minimum.

3.3 Field verification of achievable head position

By placing a test subject face down, with their head and trunk exposed, but their pelvis and legs still fully buried in the snow, we evaluated how much rotation of the upper body was feasible and how it can be practically achieved by a single rescuer.

3.4 Work allocation and cadence iteration

The preferred approach is one rescuer dedicated to continuous ventilations with a rate of 8 - 10 ventilations per minute, while a second rescuer continuously excavates the remaining body. Field scenarios tested the most common initial constraints: the tip of the Snow Conveyor Belt is too narrow for two rescuers to perform these two tasks simultaneously, or there simply is not a second rescuer available. One rescuer therefore had to alternate between 'ventilation mode' and 'excavation mode' to free the body from the pelvis downwards. This operational requirement produced the intermittent ventilation (iVent) protocol.

Successive field test iterations examined the duration between the set of five rescue breaths. Each change from excavation to ventilation and back required repositioning, restoring the airway and seal, and then resuming effective shoveling.

Since estimating the digging interval during strenuous work is unreliable, and timing devices aren't practical, the rescuer was instructed to internally count at a 1-second rhythm after the fifth breath. When 30 seconds of measured excavation time had elapsed, the timekeeper of the field test gave a signal to the digging rescuer to report the count at loud voice. This process or data collection was repeated over several days of trials.

4. RESULTS

4.1 Burial position

Interviews of experienced avalanche rescuers confirmed the conclusions of Kornhall et al. (2016) concerning prone burial position. Expert interviews suggested that the most probable burial position is face down, with the head pointing downslope toward the valley and the body's long axis lying approximately parallel to avalanche

flow. Burial positions perpendicular to the flow appear to be linked to distinct terrain traps or collisions with objects in the flow. Vertical positions seem to be least likely, often associated with a short distance displacement at the bottom of a small, convex terrain feature.

4.2 Ventilation compatible airway position

The field trials showed that when the head of the patient is pointing 90° horizontally to the side, it is ergonomically feasible to effectively ventilate the patient. For ventilations to be effective at this angle of the airway, the upper body must be rotated so that the face points away from the rescuer. The rescuer then bends over the patient to open the airway and form a seal. For some participants, resting their head upside down on the snow, in a vertical position and perpendicular to the head of the patient was considered an advantage in keeping a stable ventilation position and seal. If the patient's face points towards the rescuer, it is ergonomically impossible to perform effective mouth-to-mouth or mouth-to-nose ventilation.

4.3 Achievable head position and rotation technique

Field trials demonstrated that a single rescuer can achieve a position that allows for effective ventilation in a patient buried prone and face down by rotating their shoulder against the pelvis. To achieve this as a single rescuer, we recommend to follow the 3-step sequence of action as shown in figure 1. Step 1: Reach with one arm below the patient; Step 2: Pull on the shoulder, upper arm, lower arm or hand to rotate the upper body of the patient; Step 3: Towards the end of the rotation motion, push on the patient's opposite shoulder to achieve a stable end position. A further benefit of this rotary motion is that the patient's head reaches a higher position at the end, which leads to a more ergonomic ventilation position for the rescuer.

Other rotation techniques were found to be unsuccessful in our field tests. In a real rescue, an improvised approach is likely to cost valuables minutes and therefore, it is important to teach this procedure properly. Before starting this rotation motion, the rescuer must consider that ventilations with the patient's head pointing 90° horizontally to one side are only possible when the rescuer is bending over the head of the patient; thus, some space for the kneeling rescuer must be available at the back of the patient.

While almost any burial position of the patient is possible, we have purposely focused on how to address the challenges of positions that are particularly difficult. Consequently, the effectiveness of saving the patient's life and preventing hypoxic brain damage is highly dependent on proper techniques and training.

We equally considered the risk of mechanical injury to the patient caused by bringing the non-breathing patient into a ventilation compatible position. The medical benefit of preventing hypoxic brain injury and cardiac arrest exceeds the risk of increasing the severity of a spine injury that was initially caused by the impact of the avalanche (Sheets et al., 2018; and Fort et al., 2026). Given the overall health and age of the population of people who are statistically most likely to get caught in avalanches, the risk of causing a primary mechanical injury to a patient who did not suffer mechanical injury during avalanche flow is negligible compared to the risk of further delay in ventilation and resuscitation.



Figure 1: Step 1, Step 2 and Step 3 of the rotation motion of the upper body of the patient.

4.4 Operational protocol conclusions

When space and resources allow, the findings suggest splitting the process into two parallel tasks: one rescuer ventilates continuously, and the other rescuer excavates continuously. This arrangement reliably permits the guideline benchmark of 8 - 10 ventilations per minute and lets the ventilating rescuer hold the head in one controlled, stable position. The successful mouth-to-mouth or mouth-to-nose position does not need to be reestablished between excavation periods, making it easier to stay within the 500 - 600 mL target tidal volume range, thus avoiding insufficient and excessive volume. ERC guidance emphasizes sufficient volume for visible chest rise and avoidance of overventilation (Lott et al., 2025; Soar et al., 2025).

When one rescuer must do both tasks, the proposed iVent sequence is: five rescue breaths -> excavate the remaining parts of the body and return to the ventilation position within 30 seconds -> five rescue breaths -> excavate the remaining parts of the body and return to the ventilation position within 30 seconds -> repeat until body is fully excavated.



Figure 2: Position of the rescuer and patient just before starting the next set of 5 rescue breaths

The internal count by the test participants during the excavation interval averaged only 20. This finding corresponds to the common saying “time flies” when one is engaged in an exciting or strenuous activity - in contrast to the subjective impression of “seemingly never-ending time” when waiting unproductively for something. In the case of avalanche rescue, the hard physical work unconsciously altered the intended 1-second rhythm count to a 1.5-second rhythm count.

Cycles in which the next set of five rescue breaths were given considerably less than 30 seconds after the previous set were operationally inefficient, because the transition time between the two different working modes took up too much of the available excavation time. The cycle of ~30 seconds excavation, five rescue breaths, ~30 seconds excavation, five rescue breaths has therefore been shown to be the best fit between practical technical rescue requirements and medical ventilation requirements.

As switching from excavation to ventilation mode takes time, the recommended practically feasible rule is to start counting immediately after the fifth rescue breath, return to the head at 15, reposition, re-establish the seal, and begin the next set of 5 rescue breaths near the ~30 seconds target. The “count-to-15 rule” is a practically feasible result from these field trials, while the 30 seconds remain as formal criterion.

5. PROPOSED USE AND TRANSITION RULES

In case the patient does not breathe normally or does not breathe at all when reaching the head, start with ventilations as soon as possible and continue to excavate the remaining buried parts of the patient. Stop iVent when another rescuer is available and has sufficient workspace to provide continuous ventilation. Stop ventilation as soon as normal breathing returns. In absence of vital signs, apply 30:2 CPR as soon as the patient is in a CPR compatible position and place (follow the AvaLife protocol).

6. DISCUSSION

We have shown that it is practically feasible to perform a medically beneficial ventilation rate while continuing the excavation effort. This can be either done by a team of two rescuers, or as a single rescuer by applying the iVent protocol. Otherwise, 5 to 10 min would pass without medical treatment while the body is completely freed leading to worse outcomes. Airway and breathing are the priorities, as avalanche cardiac arrest results in 1.8% pooled rate of CPC 1–2 if not addressed.

6.1 Ventilation: continuous target and iVent best effort

When two rescuers are available and there is sufficient space in the tip of the conveyor belt, the patent will receive 8 - 10 ventilations per minute.

In iVent, the rescuer must re-establish an effective mouth-to-mouth or mouth-to-nose position before every set of five rescue breaths. The first attempt may therefore leak or fall below the 500 mL threshold while the rescuer restores head position, airway opening, and seal.

iVent is a best-effort approach, not a claim of equivalence to continuous guideline-rate ventilation. The project hypothesis is that four successful ventilations per set are likely to provide clinically meaningful oxygen delivery compared to withholding medical treatment for another 5 - 10 minutes until the patient is fully excavated.

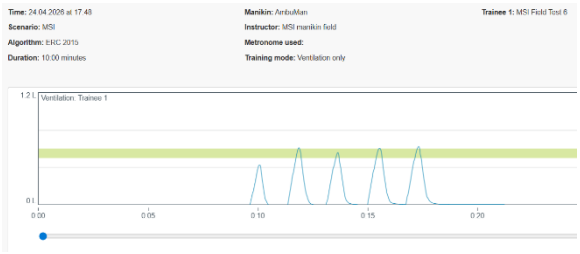


Figure 3: First rescue breath slightly too low in volume

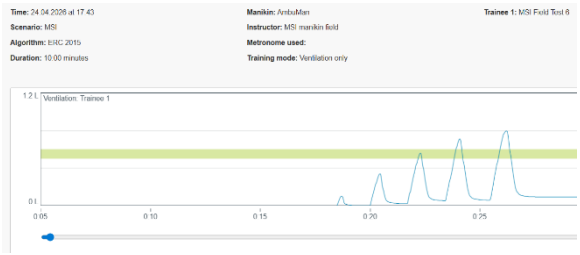


Figure 4: Initial difficulty to find the effective mouth-to-mouth or mouth-to-nose alinement or head-tilt/chin-lift position allows the rescue to only gradually increase the ventilation volume

The “count-to-15”-rule results in a 27.5 seconds excavation cycle when taking a 5 seconds transfer time from full shoveling effort to being properly positioned to give the first rescue breath into account. If only four out of five rescue breaths in each set are successful, this results in a ventilation rate of 5.65 ventilations per minute. This is at the lower end of the medically acceptable range, prompting future research to evaluate whether rescuers should extend the standard set of five rescue breaths until at least four are successful. If five out of five rescue breaths are successful, the ventilation rate is 7.05 ventilations per minute.

A patient in severe respiratory suppression or respiratory arrest is likely already in a low-flow state. The hypothesis is that reduced pulmonary blood flow leads to alveolar capillary oxygen and a carbon dioxide partial-pressure difference to be equalized already with less than the 8 - 10 ventilations per minute benchmark. Oxygenated blood returning to the left heart reaches the coronary circulation at the aortic root, so the myocardium is among the first systemic organs exposed to the

increment in oxygen content. Even a subtle improvement in oxygenation by a slow ventilation rate may therefore help prevent hypoxic cardiac arrest. As soon as the body is sufficiently freed and can be repositioned and placed in a location suitable for effective chest compressions in CPR, 30:2 CPR begins immediately if cardiac arrest is present or suspected (Smyth et al., 2025).

The approach also illustrates the value of human-factors testing. Asking participants to count to 30 seconds did not achieve precision, which lead to the "count-to-15" modification". The “count-to-15”-rule was not derived from respiratory physiology; it was a practical compensation for observed timing error. ERC 2025 education guidance supports training tailored to provider role and environment, hands-on ventilation practice, simulation, feedback, and in-situ learning (Nabecker et al., 2025). The use of a feedback manikin in realistic snow therefore fits the recommended educational-development approach.

7. CONCLUSIONS

While this research project is ongoing, our findings to date suggest that the application of the newly developed protocol (iVent), particularly when the burial duration is less than 30 min, will have a positive impact on the survival chances and neurological outcome of avalanche patients, based both on medical logic and on the practical feasibility in rescue.

The evaluation of possible and practical work positions and the basic methodology have taken up most of the field test time to date. The current data collection of 12 excavations followed by the application of the iVent protocol needs to be expanded. Scott McIntosh and Theodore Hartridge from Utah will expand the field trials to North America with their Emergency Mountain Medicine students. Data collection in Europe will also continue this coming winter. This international approach is central to MountainSafety.info, as it enables us to identify a wide range of user groups, user levels and specific situations, ensuring these challenges are adequately addressed in the development process.

However, current findings suggest that applying the current protocol, especially when the burial duration is less than 30 minutes, can improve avalanche patient’s survival chances and neurological outcomes. This is supported by both medical logic and practical rescue feasibility.

8. LIMITATIONS

This is a mannikin based study and proof of concept, which as such, does not constitute a proof of increased probability of survival or better neurologic outcome. This would require prehospital studies with humans, ideally a randomized controlled trial (RCT). However, due to ethical limitations, such studies do not seem to be reasonable. Paal et al. 2006 and 2008 have shown that providing effective rescue breaths is challenging.

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Such field trials and research & development projects are not only time- and resource consuming, they are as well costly. The Zermatt Mountain Rescue station, belonging to the Swiss Alpine Club section Zermatt, made a generous donation to support this project. Without their much-appreciated support, this project would have been in a very difficult financial situation. Special thanks go to Anjan Truffer for his initiative, which made this donation and support possible.

CONFLICT OF INTEREST STATEMENT

No equipment sponsored by manufacturers was used as part of the research project. The project increases the chances of survival and the likelihood of a good neurological outcome, thereby reducing the economic potential for avalanche, mountain, and rescue organizations as well as hospitals and air ambulance providers in favor of humanitarian goals. Work of others is properly referenced, cited and acknowledged. This approach ensures sustainability in research and avoids conflicts of interest from the outset.

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